Factors influencing regional precipitation variability attributed using an airmass trajectory method

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Precipitation accumulations England and Wales

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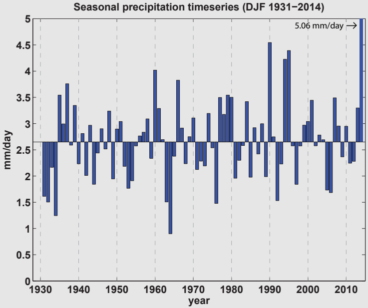
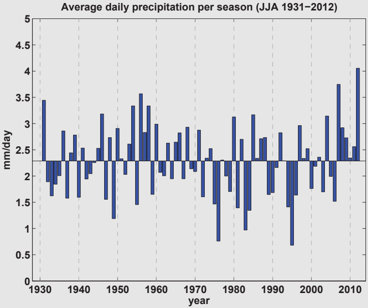




- Large variability in UK precipitation
- Several extreme seasons in the UK since 2000:
    - DJF 2013-2014 wettest winter on record.
    - JJA 2007 floods.
    - JJA 2012 record summer precipitation.

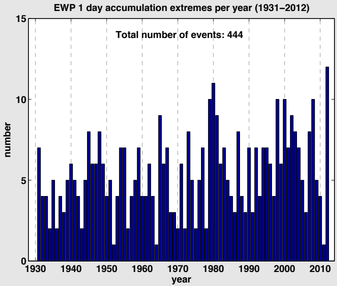
Summer precipitation trends and extremes

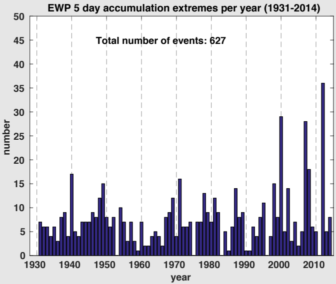
Many studies have investigated trends in observed UK precipitation totals and precipitation extremes.

[Wigley et al. (1984),Osborn et al. (2000), Maraun et al. (2009), Jones et al. (2012), De Leeuw et al. (2015)]

→ Observed trends in annual precipitation are small.

→ No trend in daily precipitation extremes is detected [De Leeuw et al. (2015)]





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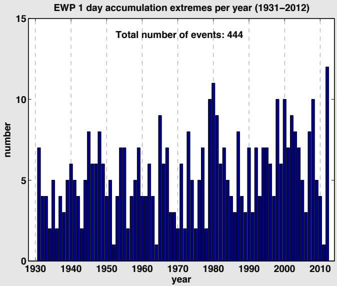

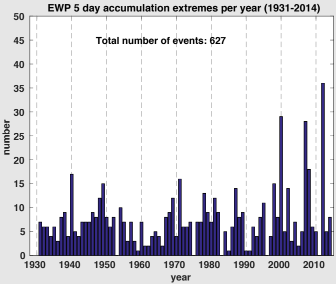

Key points

- Trends in daily precipitation extremes are small.
- Increased number of extreme multi-day precipitation accumulations.

The Research Questions

- Can we describe regional precipitation variability quantitatively using a physically-based framework?
  - What mechanisms are responsible for observed precipitation variability?
  - How to combine them to determine their total impact on precipitation?

Only variability in **monthly** accumulations is considered in this study.

Reading Offline Trajectory (ROTRAJ) Model

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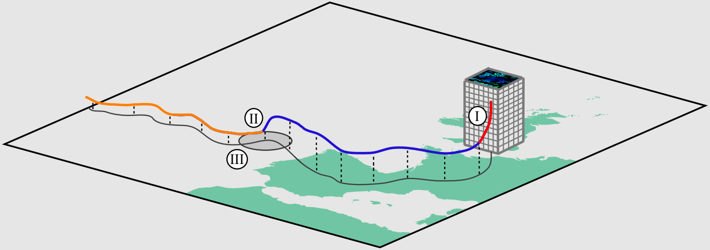

- Calculate 3D back-trajectories using analysed winds [Methven et al., 2003]
- Reanalysis: ERA-Interim (T255L61, Linear Gaussian Grid)
- Domain investigated: Western Europe $[43N, 59N] \times [14W, 7E]$
- Arrival grid spacing: $0.25^{\circ} \times 0.4^{\circ}$. (32 levels, 25hPa) $\rightarrow$ **110240 trajectories**
- Relevant quantities from ERA-Interim stored every 6 hours over the length of 8 days **(JJA 1979-2013)** $\rightarrow$ **1.5 billion trajectories**.

Trajectories: Relate Δq & precipitation

$$\Delta q_i = q_i(0) - q_i(-t)$$

$$\mathbf{P} = -\sum_{\mathbf{i}=1}^{\mathbf{n}} \mathbf{A} \times \Delta \mathbf{q_i}$$

- Precipitation in arrival column
- Summation over column
- Constant to convert *g/kg* to *mm*
- Negative change in specific humidity over last 6 hours

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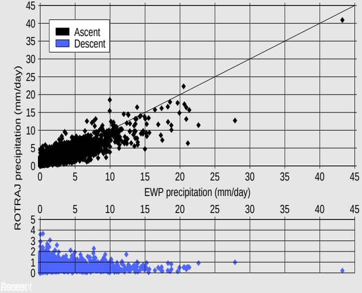

Comparison of rain gauge observations (EWP) with the ROTRAJ rain estimates for 24 hour accumulations.

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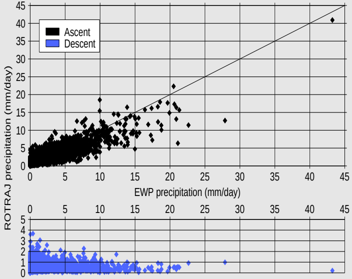
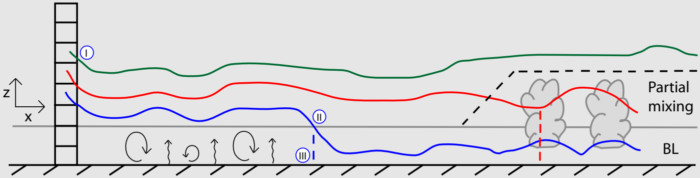


ROTRAJ vs. Observations

- ROTRAJ represents the temporal variability (r=0.88), but underestimates England and Wales Precipitation observations by 22%.
- Δq along trajectory good precipitation proxy.

Defining the origin location

- Interested in point where surface processes last influence the air mass properties.
- Last exit of the boundary layer (BL) sets the properties.



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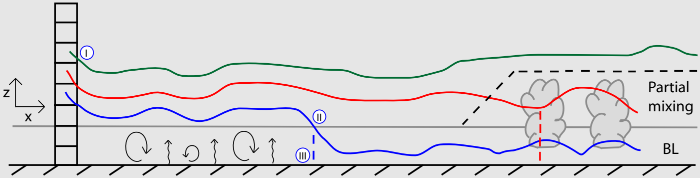
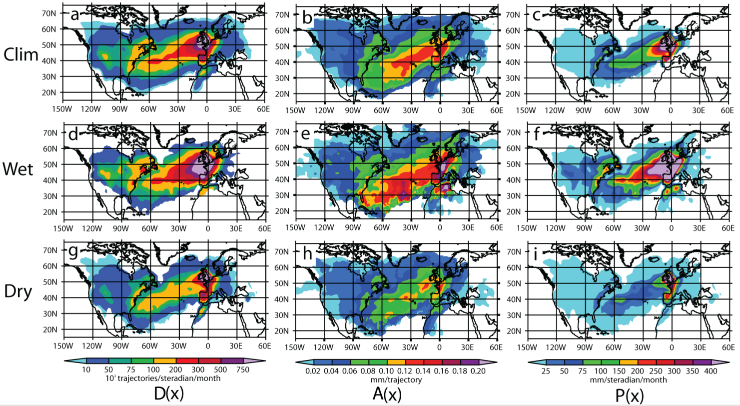


- Since BL mixing is rapid, specific humidity is a maximum on last exit and connected to the surface directly below.
- History prior to exit does not influence precipitation at the arrival region.
- **NOT** attempting source attribution of water molecules.

Origin maps JJA 1979-2013



- $D(x)$: Trajectory origin number density
- $A(x)$: Average precipitation contribution per trajectory
- $P(x) = D(x) \cdot A(x)$: Total precipitation contribution

Trajectory-based diagnostics

The integrals of $D(x)$ and $A(x)$ are related to three model metrics:

$$\int D(x)dx = M_w \cdot n_w$$
$$\int A(x)dx = \overline{p_w}$$

- M_w: Average mass of precipitating trajectories per record
- n_w: Number of wet records
- $\overline{p_w}$: Average precipitation per trajectory

The considered physical mechanisms

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In this study we consider 5 different mechanisms:

- Change in moisture loading of the precipitating air masses via temperature changes following:
  - Change in air-mass 'origin' conditions (**ST**)
  - Change in air-mass 'origin' location (**LOC**)
- Intensity of precipitation (large scale ascent) (**AI**)
- The extent of the large scale ascent (**AS**)
- Number of wet analyses (>1mm/6hrs) (**NT**$_w$)

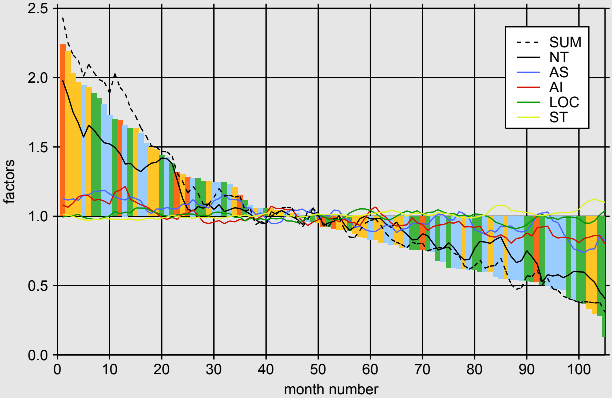
Proposed framework

$$P_{act} = \; < P > \cdot \; \underbrace{ST \cdot LOC \cdot AI}_{\frac{\overline{p_w}}{<\overline{p_w}>}} \cdot \underbrace{AS}_{\frac{M_w}{<M_w>}} \cdot \underbrace{NT_w}_{\frac{n_w}{<n_w>}}$$

$< .. >=$ climatological average for the region

The factorisation

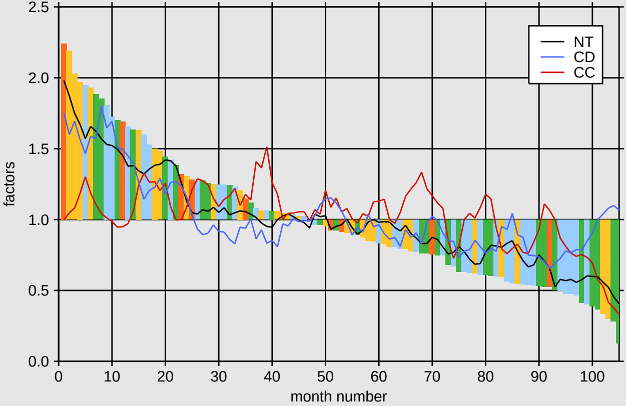
The ranked EWP observations and the ROTRAJ precipitation estimate (JJA)



- Combined factors describe 83-89% of the observed variability.
- Results show that intensity and areal extent of precipitation events are not exceptional; the event count (NT_w) dominates the signal.

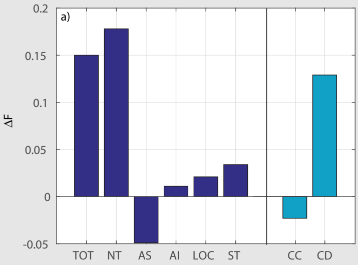
Investigation of the NT_w factor

- Used a cyclone tracking algorithm (TRACK[1]) to determine cyclones impacting England and Wales.
- Relate NT_w to cyclone count (CC) and duration (CD) across the UK.

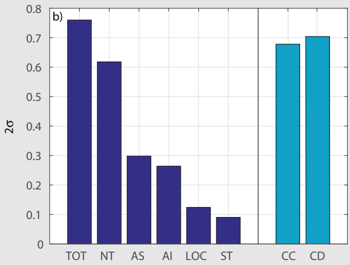


[1] [Hodges et al. 1994], via Dr. M. Hawcroft

Are the factors similar when considering decadal variability?



a) Seasonal average difference between the warm phase (1996-2013) and cold phase (1979-1993) of the AMO for each factor.



b) Interannual variability (represented by 2σ).

- Decadal change also resulting primarily from increased cyclone duration.
- Direct thermodynamic factor ST is positive but only accounts of 1/5 of precipitation signal.

Conclusions

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- Trajectory-based framework is able to describe 83-89% of observed UK precipitation variability by physical factors.
- Number of wet records dominates wettest months, rather than intensity and areal extent of precipitation events or anomalous air mass origin properties.
- Precipitation is greater in a decade with higher SST (ST > 0), but increased cyclone duration factor is 6 x the direct thermodynamic factor.

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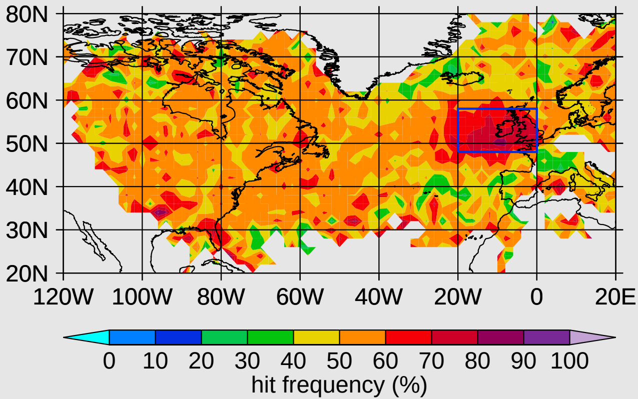
Overall conclusion

Precipitation variability at the end of the storm track is dominated by changing storm statistics, rather than warmer air-mass origins.


80N
70N
60N
50N
40N
30N
20N
120W
100W
80W
60W
40W
20W
0
20E
0
10
20
30
40
50
60
70
80
90
100
hit frequency (%)